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Final Report CANUSA West Spruce Budworm Program

May 1979

Preliminary Evaluation of an Electronic Guidance System for Use in Aerial Spraying Against the Western Spruce Budworm

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1. Summary

This report presents a preliminary evaluation of an electronic guidance system for use in aerial spraying over complex terrain. Several techniques were evaluated for tracking and plotting the path of an aircraft during simulated spray passes. A series of "Flatland Terrain" tests were designed to evaluate two tracking systems and the performance of an electronic guidance system over flat, clear farmland. A series of "Complex Terrain" tests were designed to evaluate accuracy of the flight paths with and without the assistance of an electronic guidance system. The output from the electronic guidance system provided X,Y position data at 1/2 second intervals. The digital position data was recorded on a modified portable magnetic tape recorder and results were plotted which gave an accurate record of the flight path. The "flatland terrain" tests revealed that the electronic guidance system could enable a pilot to fly parallel evenly spaced swaths with an average deviation of 9% of the desired swath spacing. The "Complex Terrain" tests showed that the pilot was unable to fly parallel evenly spaced lines; however, the pilot did gain some assistance from the gudiance system over complex terrain. The pilot maintained an average deviation of 66% of the swath for the best test with the guidance system and was only able to achieve a deviation of 153% of the swath for the best test without the guidance system.

2. Introduction

One of the basic factors required for uniform distribution of sprays from agricultural aircraft is that the aircraft must fly a uniform predetermined swath spacing. In flatland agricultural areas, the aircraft operators have relied upon flagmen to progressively mark each swath. In forested areas, and particularly in complex terrain, it becomes very difficult to manually mark each swath. Typical operations in forested areas are conducted with markers, such as tethered balloons, to identify the corners of spray blocks and pilot judgement is relied upon to fly parallel even-spaced swaths within the block. Even with experienced pilots and small blocks, the swaths are frequently overlapped, not in sequence, and with some large skips (J.W. Barry, Ag-Av. 18(3) July '77).

Recently, several electronic guidance systems have been introduced on the market to provide progressive swath guidance at any desired swath spacing. The manufacturers claim an accuracy of $\pm$ 10 ft. up to a distance of 50 miles from the base stations. No quantitative information was available on the performance of these electronic (line of sight) systems for use in mountainous terrain. Thus, there is a need to determine if available electronic guidance will improve the aircraft performance capabilities in mountainous terrain as compared to present methods which depend on pilot judgement and inadequate swath marking by balloons, flags, lights, etc. The evaluation of the system should determine if the system can assist the pilot to: (a) locate the block to be treated, (b) locate desired evenly-spaced swaths, (c) locate boundaries where spray should start and stop, (d) locate exact point where spraying stopped at end of load to recommence spraying after refilling.

The major objectives of this study were to:

(1) Evaluate several techniques for tracking or plotting and recording the location of an aircraft during individual spray passes. The system or systems which appear to be most feasible will be used for evaluation of guidance systems in open flatland tests and also the tests in complex terrain.

(2) Evaluate the performance of a selected aerial electronic guidance system operated over flat, clear farmland. The tracking system selected under Objective 1 (above) would be used to determine usefulness and accuracy of the system.

(3) Evaluate the performance of the electronic guidance system over complex terrain. Flight lines with the use of the electronic guidance system will be compared to lines flown without the guidance system but with the corners of the block marked with flags.

3. Methods and Design of the Tests

The first step involved a review of the literature and other possible techniques that are available to track and plot the path of an aircraft during successive flight passes over simulated spray blocks. The following techniques were evaluated for potential use on this project: 1) radar, 2) two theodolights, 3) photographs-- side view from fixed location, 4) photographs -- aerial view from another aircraft flown above the spray plane, 5) surveyors plotting table, 6) precision optical range finder, 7) surveyor's pulsed electronic measuring equipment, 8) radio wave triangulation system, 9) TV video recording from another aircraft flown above spray aircraft, 10) dyed spray emitted from one large central jet on aircraft, 11) recording position data from electronic guidance system.

The last two techniques, 10) and 11), were selected as the most feasible system for tracking and evaluating the guidance systems for this project.

The next step involved selection of the guidance system and aircraft. The "Flying Flagman", Del Norte Technology, Inc., was selected based on the availability and experience of an agricultural aircraft operator located near Fresno, CA, who had operated two systems mounted in Ayres Turbo Thrush ag aircraft, and had one system in a Piper Arrow aircraft for pilot training. The company had experience operating the systems for about six months and had used them for both night and day agricultural spray operations on the west side of the San Joaquin Valley west of Five Points, California.

A. Flatland Terrain Tests

This series of tests was designed to determine the performance of the guidance system using two independent measurements of the flight path over ideal open flatland conditions. An Ayres Turbo Thrush aircraft, fitted with a Del Norte Flying Flagman System, was provided through the cooperation of Gary Rockwell, Carberry Dusters - Westside operation near Five Points, CA. The pilot was Gail Nebker. He is a veteran ag pilot with several thousand hours of ag operation and with six months of experience with the Del Norte system.

The two systems for determining the flight paths were: 1) the dyed spray system. This system consisted of using a whitewash slurry containing 1 lb of Ortho "Sun Shield" per 1 gallon of water. Two aircraft loads, with a total of 650 gallons of slurry, were used on the three plots. The slurry was pumped through the system and ejected out through a 2-inch diameter opening in the spray line located below the fuselage and at the center of the aircraft. The whitewash produced a heavy visible band about 2 ft wide on the ground and vegetation. 2) recording of the position data from the guidance system. A portable, cassette-type magnetic tape voice recorder was modified to accept the digital position data measured by the Del Norte system. The time interval between successive position data was 1/2 sec. The main computer frame provided two types of position data, X-Y position and Range from each transponder. For this set of tests the X-Y data was recorded. In this mode, after the pilot has flown and entered the positions P_1 and P_2 for the beginning and end of Pass No. 1, the subsequent X-Y data provides the position data with the (0,0) coordinate at P_1 and the Y axis along the line between P_1, P_2.

Three plots, each 1800 x 900 ft, were established in two adjacent 160 acre blocks of alfalfa on the Jubil Farm, Fig. 1. Figure 2 shows the distances and geometry of the plots with respect to the base line through the two ground transponders. It should be noted that due to the geometry of the aircraft position calculations, it is recommended that the lines to the transponders be within a range of 30 to 60° from the baseline between the transponders. Original plans for the selected plots called for the use of another transponder in place of No. 1. However, the day of the tests the other transponder failed and the transponders used (Fig. 2) had a larger angle than desired. The pilot flew a preliminary flight to verify that he could satisfactorily use the transponders. Flag markers were placed at P_1 and P_2 for each plot. The alfalfa was cultivated in rows that were perpendicular to the flight path and the P_1, P_2 positions were established about 400 ft inside the field boundary. Thus, the pilot did not have a precise visual reference to assist in swath alignment or turning the spray on and off.

The pilot was instructed to enter P_1 and P_2 over the two marker flags, then to proceed to use only the guidance system to fly 10 consecutive passes at a 100 ft spacing and at a height of 5 to 10 ft. He was asked to turn the spray

Map of Flatland Plots.

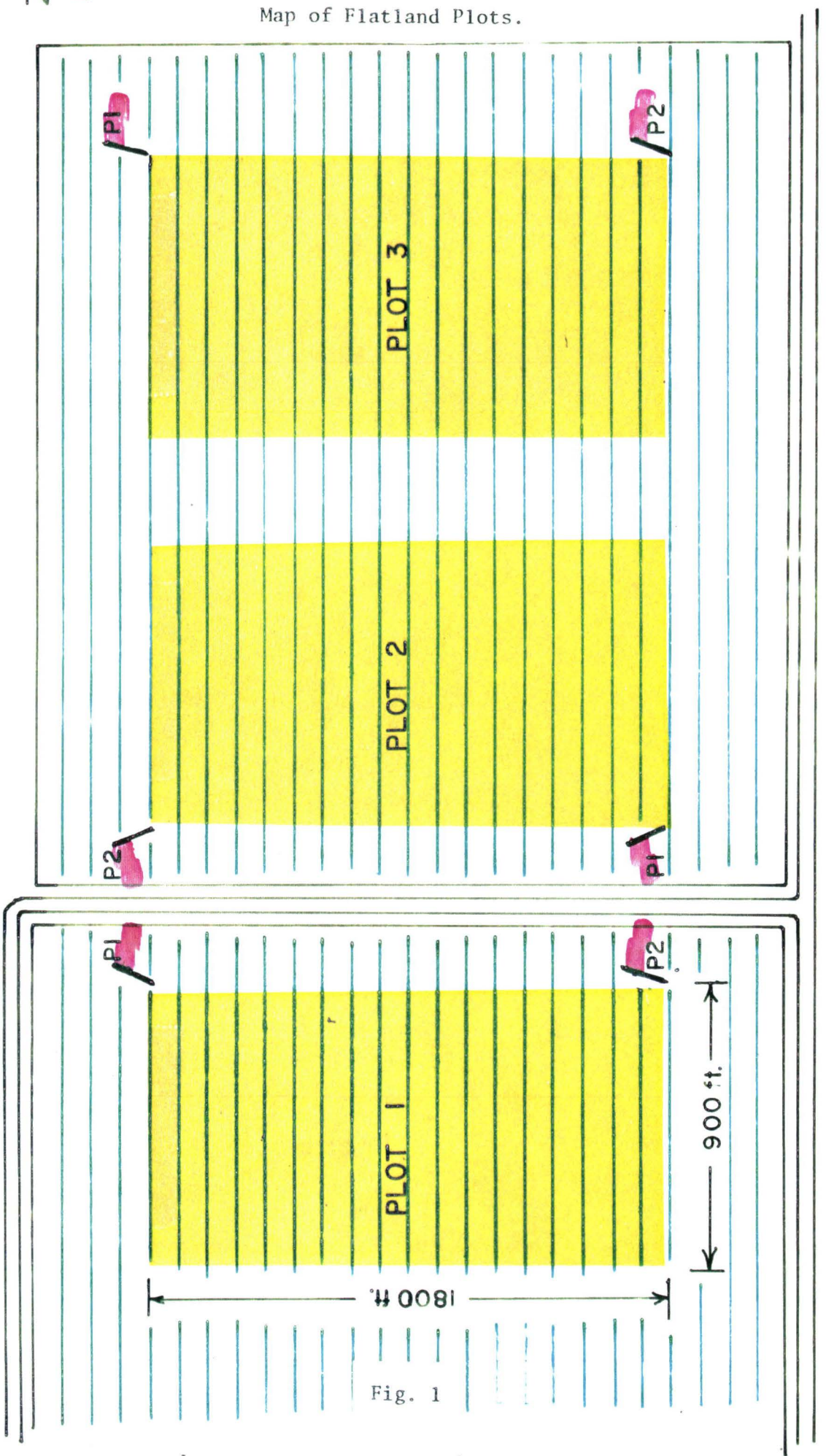

Fig. 1

Location of Transponders and Flatland Plots.

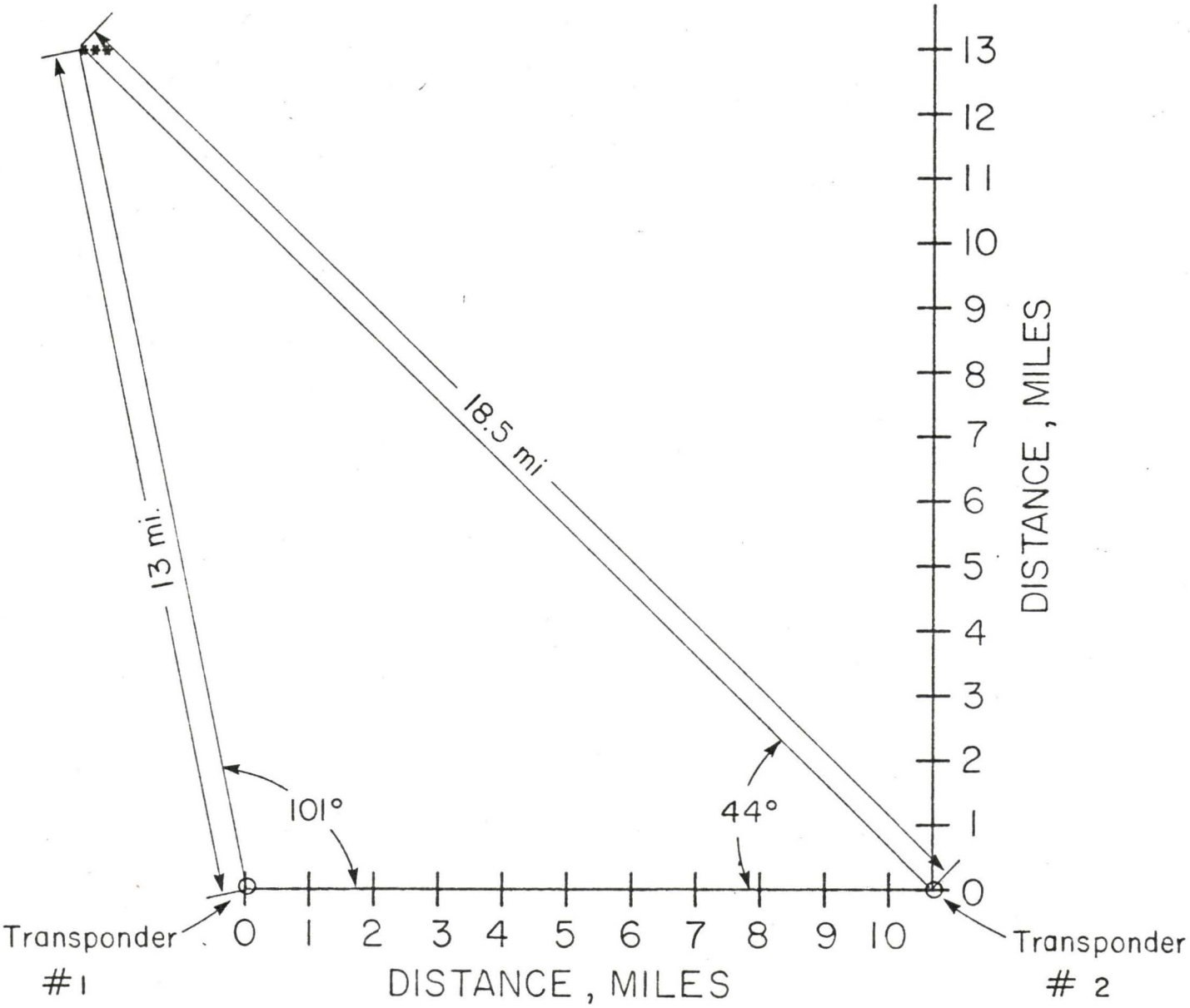

Fig. 2

on and off based on the signal from the guidance system. Also, on Pass No. 5, he was requested to spray about 1/3 the length of the pass, then abort to simulate an empty tank. Then he was asked to attempt to return to the location of Pass No. 5 and commence spraying at the point he stopped spraying the previous time. He was asked to repeat this sequence for each plot.

After the applications, four sample lines were established within each plot to measure the spray deposit line. The sample lines were established perpendicular to the flight line through P_1, P_2 and intersecting it at a distance of 120, 600, 1200 and 1680 ft from P_1. During the applications, there was a low crosswind component from the west. Thus, all measurements were made to the west side of the heavy deposit line. This side provided a very distinct line since any fine drops were displaced to the east. Thus, the distance along the sampling line to the western edge of each spray line was measured.

B. Complex Terrain Tests

This series of tests were designed to evaluate if an electronic guidance system could significantly improve the pilot orientation, improve the uniformity of swath spacings and generally improve the spray coverage for aerial applications over complex terrain.

A 4-place Piper Arrow aircraft fitted with a Del Norte Flying Flagman system was used for these tests. This aircraft permitted an observer to accompany the pilot. The observer was able to operate the magnetic tape recorder, change tapes, make notes on the operation and give direct instructions on the sequence of plots and tasks desired. The pilot was Roy Dillon, formerly chief pilot and general manager of Carberry Crop Dusters. He is a veteran ag pilot with several thousand hours of ag operation and had used the system in the Arrow to demonstrate and train Carberry pilots on the use of the Flying Flagman.

The modified portable magnetic tape recorder used in the first tests was used to record the position of the aircraft for all tests. The X-Y output from the main computer frame was not available, thus the Range from each transponder was recorded. A Hewlett-Packard 9825 calculator system was programmed to compute the X,Y position and plot the position data obtained at 1/2 sec intervals for each pass over the simulated spray plots.

A total of five plots were established in a variety of complex terrains in the foothill area near Coalinga, CA. Figure 3 shows the plots on a topographic map. As shown, the plot elevations ranged from 1300 to 600 ft. Plots

Map of Complex Terrain Plots.

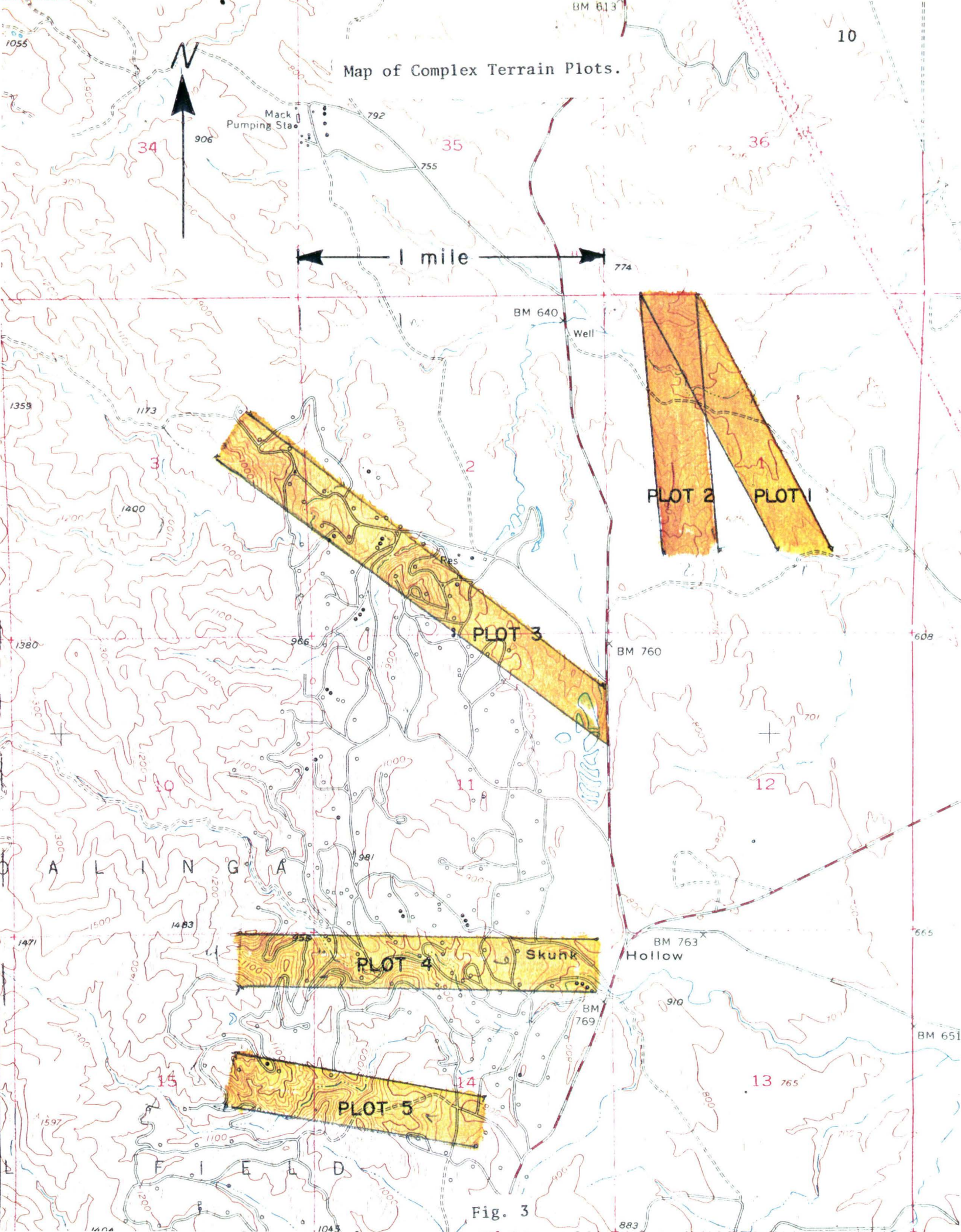

Fig. 3

1 and 2 were flown twice, once with the assistance of the guidance system and once without the guidance system. Plots 3 and 5 were flown with the guidance on and Plot 4 was flown without the guidance system. Thus, a total of 7 blocks were flown, 4 blocks with guidance on and 3 without the electronic guidance system. It should be noted that the guidance system was used to record the position of the aircraft during all flights, but the guidance indicator was covered to prevent the pilot from using the position information for the "guidance off" tests.

The flight sequence was identified by the Run number. Table 1 shows a summary of the sequence of all the flights. Only two flags were used to mark the P_1, P_2 boundary of the plots that were flown with the assistance of the guidance system. Four flags were placed on the four corners of Plots 1 and 2 to assist the pilot for the guidance "off" tests. Three corners were marked with flags on Plot 4 which was also flown with guidance "off".

The pilot was instructed to make eleven passes over each block with the first pass over P_1 and P_2. He was requested to make the next ten passes parallel to P_1, P_2 and progress with a 100 ft swath spacing.

Figure 4 shows the distances and geometry of the plots with respect to the base line through the two ground transponders. The transponders were left in the permanent locations used by Carberry Dusters for the flat valley applications. The two above plot locations were selected to obtain a nearly clear line of sight to the transponders. The pilot was also instructed to fly well above peaks to minimize obstructions or reflections of signals between aircraft and transponders.

4. Results and Their Significances

A. Flatland Tests

Immediately after the three plots were completed the cassettes were taken to our portable laboratory with a H.P. 9825 calculator and plotter system. The quality of position data was verified by making a real time plot of the flight paths. The digital X,Y data from the Del Norte guidance system was recorded to the nearest one tenth of a meter. A sample of the X,Y data for Passes 1-5 of Plot 3, along with the listing of the deviations from the theoretical line are shown in Table 2.

Figures 5, 6 and 7 show plots of the digital data from the "Flying Flagman" and the measured spray deposits on the four transects for Plots 1, 2 and 3,

Table I

Run No.	Plot covered	Electronic Guidance assistance "ON" or "OFF"
1	1	ON
2	2	OFF
3	3	ON
4	5	ON
5	4	OFF
6	1	OFF
7	2	ON

Location of Transponders and Complex Terrain Plots.

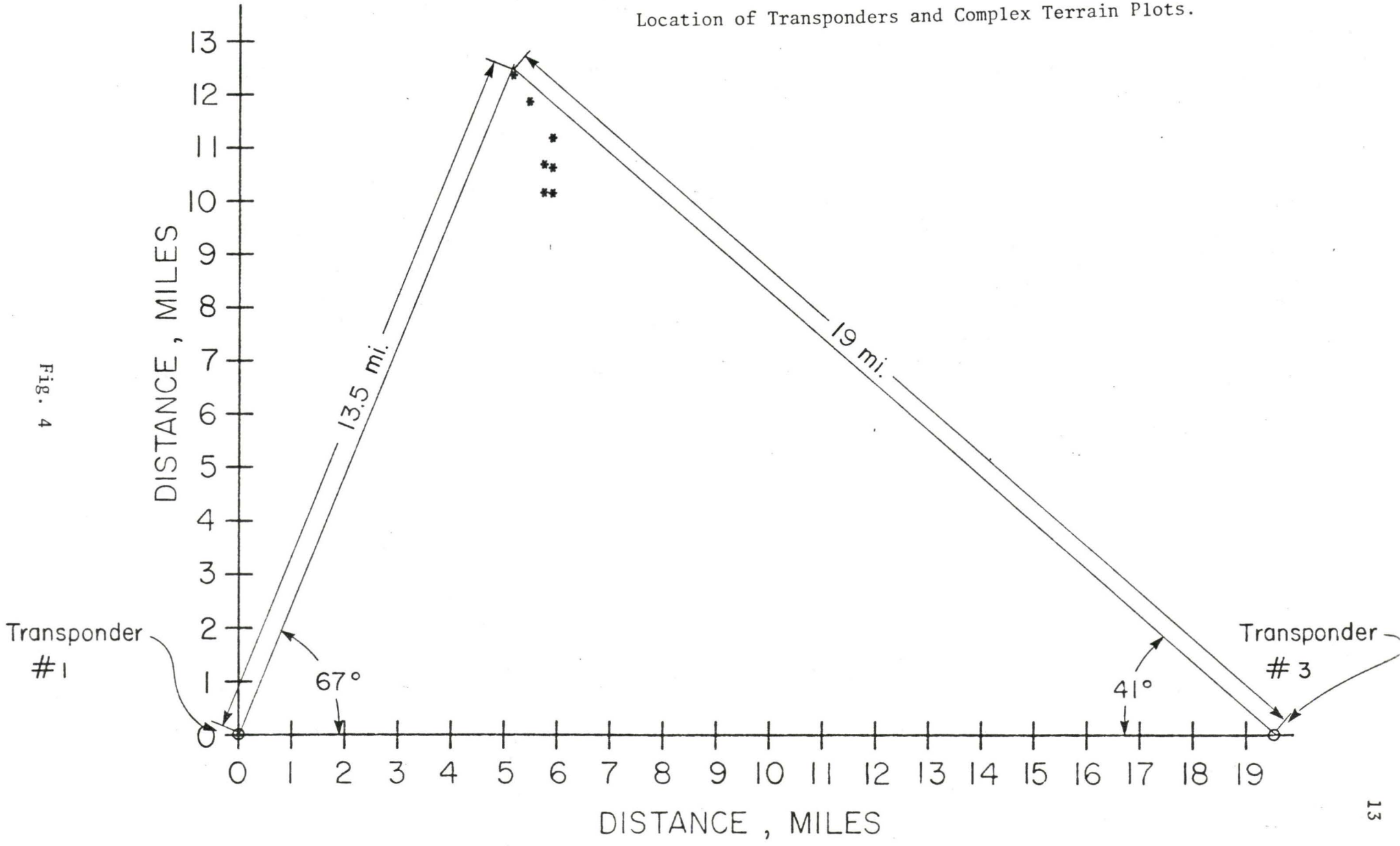

Fig. 4

Table 2

RUN 3 P2-P1 = 581 METERS

DATA LISTING

PASS 1	PASS 2	PASS 3	PASS 4	PASS 5
0.3,569.3	34.9, 2.3	58.2,560.9	92.1, 7.8	121.4,570.9
-0.5,538.5	35.2, 37.1	57.6,528.5	92.1, 44.7	120.4,540.1
-0.4,508.2	35.5, 71.4	57.9,497.2	92.8, 82.3	119.5,510.1
-0.8,477.2	37.0,106.5	59.1,467.5	92.7,117.7	119.1,480.9
0.8,448.8	38.0,140.7	59.6,436.7	92.2,153.4	119.3,453.0
0.7,419.3	38.2,174.4	59.7,405.3	91.6,190.0	119.3,423.9
0.8,389.3	38.5,209.0	60.3,373.9	91.9,226.6	119.4,394.1
0.2,358.6	37.7,242.7	60.8,342.9	92.6,263.1	119.1,364.8
1.0,328.6	37.5,277.1	61.1,311.2	92.4,298.6	118.7,335.5
0.9,297.8	36.8,311.8	61.4,279.1	93.2,336.1	119.0,306.3
0.4,266.1	36.5,346.9	63.2,248.6	93.1,372.1	119.0,278.0
0.5,235.0	36.3,382.2	62.8,215.6	92.3,406.6	118.2,247.8
1.5,205.4	36.0,416.4	63.1,184.7	92.1,441.6	118.6,219.3
0.5,173.6	36.3,451.7	63.3,153.2	91.9,477.5	118.5,189.8
0.5,142.7	36.8,487.2	63.8,121.7	92.7,513.8	118.3,160.7
1.0,112.5	36.4,520.9	63.1, 88.9	92.3,549.0	118.7,131.8
0.9, 82.1	37.4,555.0	62.6, 56.2		118.9,103.6
0.8, 51.5		63.5, 26.4		117.5, 72.8
0.2, 20.3				117.5, 44.3
				117.8, 15.2

CORRECT POSITION				
0.0	30.5	61.0	91.4	121.9
AVERAGE POSITION				
0.5	36.8	61.2	92.4	118.9
MINIMUM DEVIATION				
0.2	4.4	0.1	0.2	0.5
MAXIMUM DEVIATION				
1.5	8.0	3.4	1.8	4.4
AVERAGE DEVIATION				
0.7	6.3	1.8	0.9	3.0

Aircraft Path Data from Flying Flagman and Spray Deposits on Plot 1.

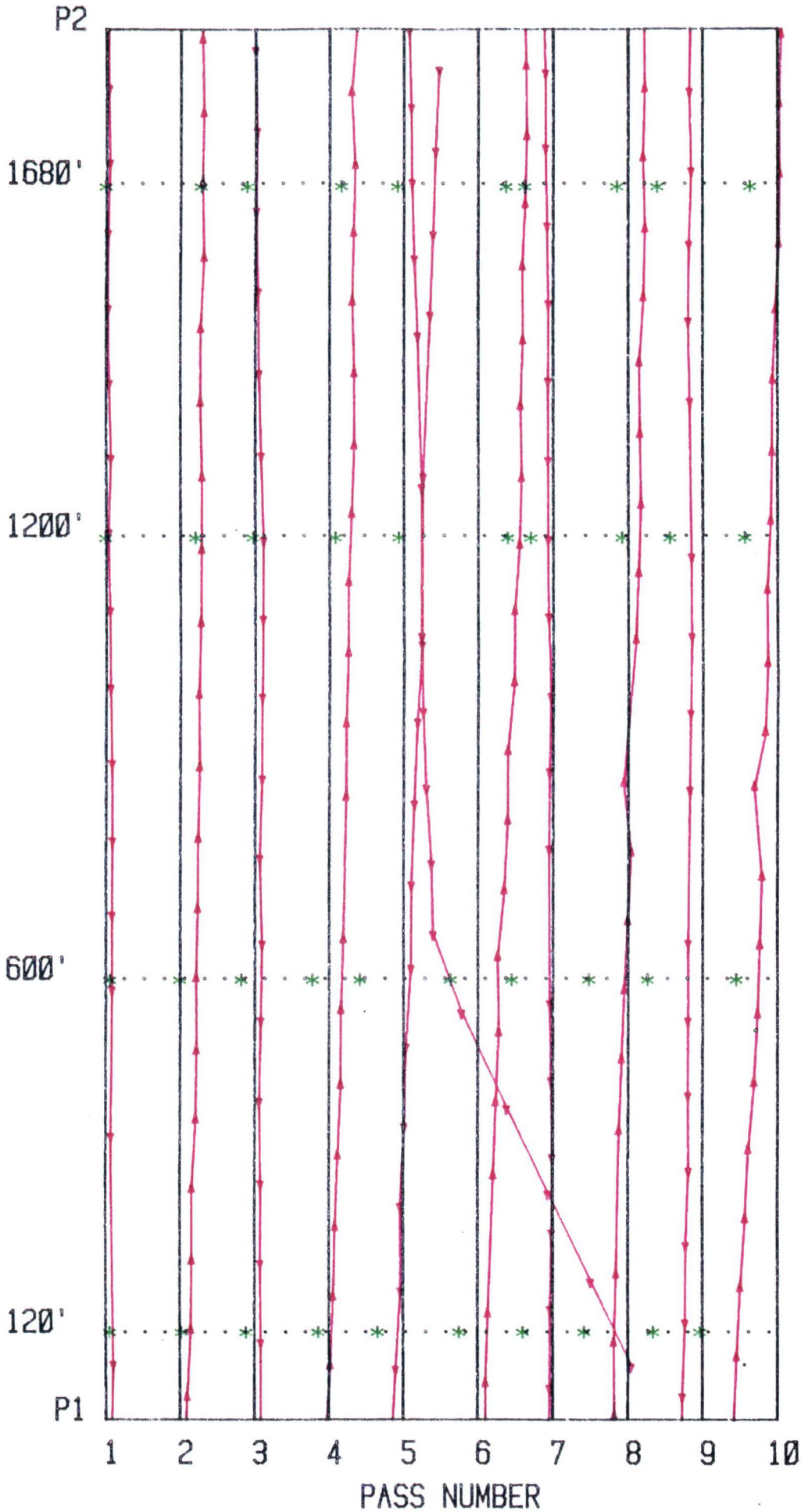

Fig. 5

Aircraft Path Data from Flying Flagman and Spray Deposits on Plot 2.

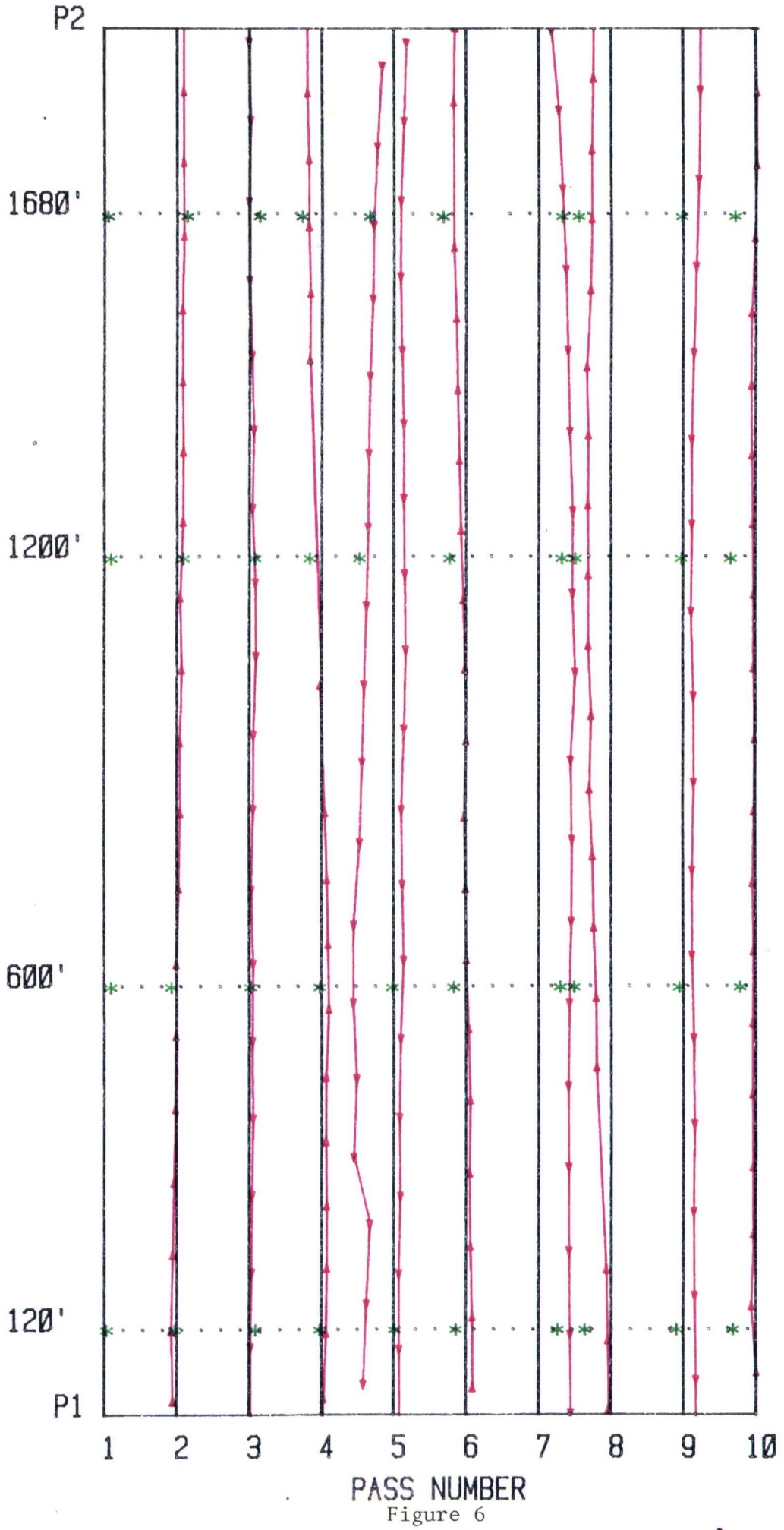

Figure 6

Aircraft Path Data from Flying Flagman and Spray Deposits on Plot 3.

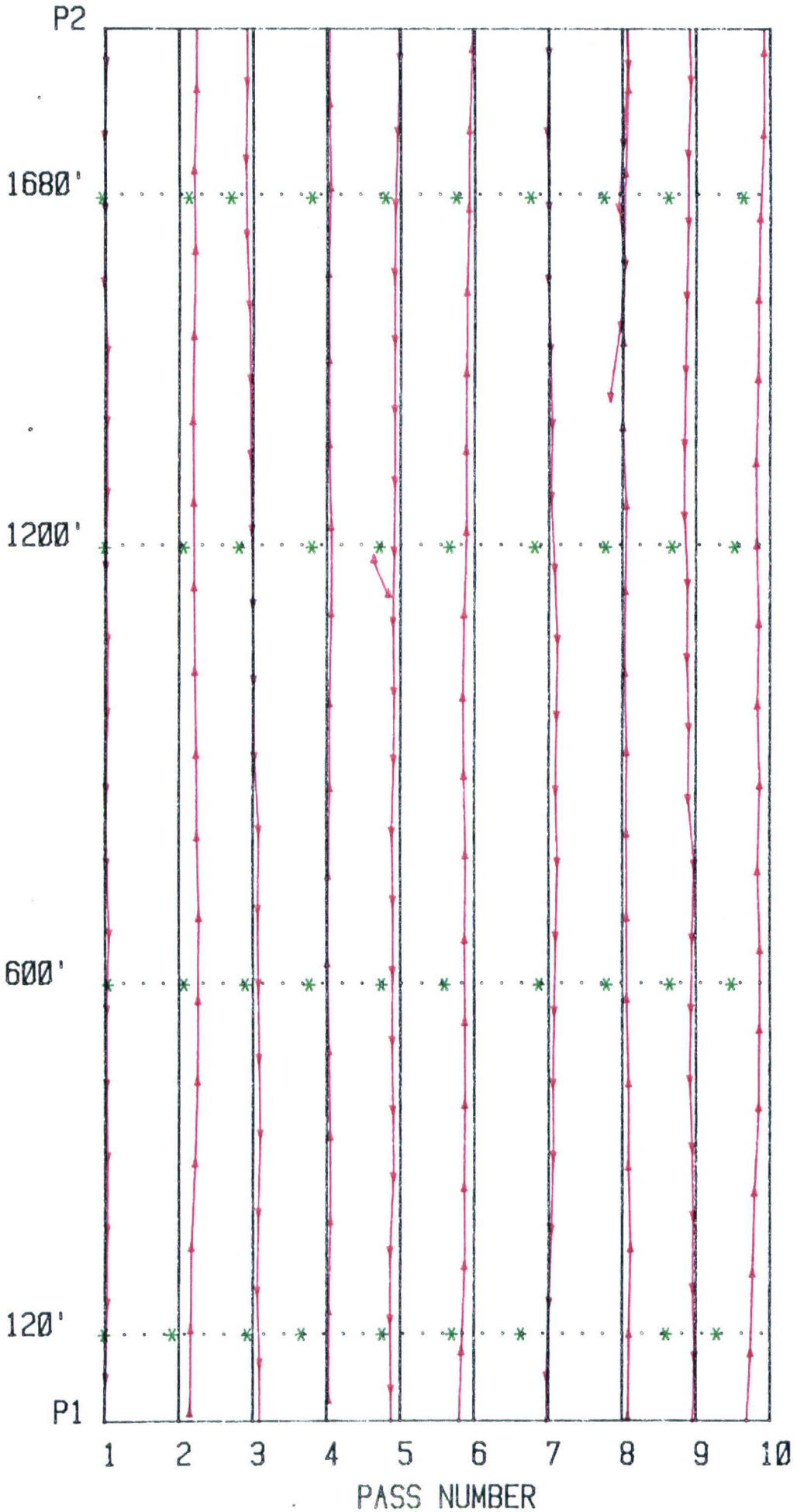

Figure 7

respectively. Each small arrowhead on the red line indicates the X,Y data from the Flying Flagman at 1/2 second intervals. The arrowhead indicates the direction of travel. Occasionally there are some skips due to rejection of bad data. This may occur due to reflections, obstructions (such as trees, buildings, etc.) in the path or a change in plane's altitude which may block out the antenna's reception. The Flying Flagman was programmed to extrapolate or predict the path for at least 3 skipped data points in an effort to minimize needle fluctuations from a few rejected values.

The pilot selected a needle sensitivity of $\pm$ 100 ft for above tests. Most pilots prefer to use a sensitivity equal to the swath spacing but this is not necessary and a more accurate swath spacing may have been possible with a more sensitive needle. This pilot had been normally flying with a swath spacing and sensitivity of 40 ft.

On Plots 1 and 2 the pilot attempted to follow instructions and abort the spraying on Pass 5, circle, and return to the simulated empty tank location. Plot 1 shows the left turn out at about 2/3 the length and the very close return and completion of the "5th" swath. Unfortunately, the light indicating the exact position to resume spraying was inoperative and we could not evaluate the resumed spray position performance. The pilot did attempt to try the "return to" location on Pass 5 of Plot 2, but again it was inoperative. This problem probably explains the reason for his greater deviation on the second pass of Swath 5 on Plot 2. The pilot did not attempt the return flight on Plot 3.

Table 3 summarizes the results of deviations of the aircraft positions from the recorded Flying Flagman output and the theoretical desired line at a 100 ft swath spacing for all three plots. This table basically illustrates the "pilot error" or how accurately the pilot can fly a theoretical computed course. Plot 3 illustrates a very acceptable performance with an average absolute deviation of 9 ft which represents an average deviation of 9% from the prescribed swath spacing.

The green stars on Figures 1, 2 and 3 represent the positions of the measured spray deposits. The data generally follows the position data from the Flying Flagman. However, on close inspection it was noticed that the spray deposit data was almost exactly the same for the first pass and was progressively somewhat shorter for each pass up to Pass 10. This progressive difference could be explained by a "calibration" error within the Flying Flagman. Table 4 summarizes the cumulative error of the Flying Flagman over the full application width

Table 3. Deviations of the aircraft position from the Flying Flagman and the theoretically desired line at a 100 foot swath spacing.

FLATLAND TERRAIN TESTS - GUIDANCE ON

Pass No.	Plot #1 Max. Dev. in feet	Plot #1 Min. Dev. in feet	Plot #1 Ave. Dev. in feet	Plot #2 Max. Dev. in feet	Plot #2 Min. Dev. in feet	Plot #2 Ave. Dev. in feet	Plot #3 Max. Dev. in feet	Plot #3 Min. Dev. in feet	Plot #3 Ave. Dev. in feet
1	10	2	5	--	--	--	5	0	2
2	31	9	23	9	0	6	26	14	21
3	10	0	6	9	0	4	11	0	6
4	34	1	21	20	0	10	6	0	3
5	26	0	12	38	7	19	14	2	10
6	64	10	42	18	0	7	18	4	12
7	11	2	6	50	27	41	11	0	5
8	22	0	13	34	4	25	10	0	5
9	28	15	20	24	10	15	16	3	10
10	55	1	21	7	0	4	27	9	17
Average Absolute Deviation	29	4	17	23	5	15	14	3	9

Table 4. Lateral distance from P_1, P_2 line in feet for a cumulative of nine swath spacings measured on four transects.

		1	2	3
	Transect distance from P_1	Measured spray deposit ft.	Recorded position from "Flying Flagman", ft.	Deviation of "Flying Flagman" position from measured spray deposit
Plot 1	120	800	845	45
	600	845	873	28
	1200	857	886	29
	1680	861	900	39
Plot 2	120	870	896	26
	600	880	896	16
	1200	868	896	28
	1680	871	899	28
Plot 3	120	829	872	43
	600	848	884	36
	1200	853	882	29
	1680	867	888	21
Average		854	885	30.6

of 9 passes for Plots 1, 2 and 3. The average deviation of the Flying Flagman position data for the 9th pass was 30.6 ft. This represents a calibration error of 30.6 ft in 854 ft or an error of about 3.6%. After the tests were completed, a Del Norte representative ground checked the system over a known distance and said there was a calibration error of 500 m in 7619 meters. The representative indicated he was correcting the calibration at that time.

Table 5 illustrates the data collected on the visual observation of the accuracy in turning the spray on and off at the ends. As shown in Plot 2 the beginning of the spray swath extended inside the boundary and the end continued past the border. This was probably because the pilot was not accustomed to using the boundary indicator and did not take into account the delay or lag in the system. In general, the errors in the spray boundaries ranged from 126 ft to a "0" ft error.

It should be noted that the speed of the aircraft directly affects the absolute accuracy in swath length performance. The inherent computer update rate of the Flying Flagman is 1/2 sec which represents a distance of 95 ft of travel at an airspeed of 130 mph. Thus, the overall maximum error in starting could be the inherent computer delay in update plus the human response time. Another indication of the overall error in length was obtained from comparing the recorded length of P_1, P_2 and the accurate measured distance of 1800 ft between the markers.

The recorded distance between P_1, P_2 from the Flying Flagman for the three plots was 1890, 1939 and 1906 ft, respectively. The "calibration" error that was determined above, + 3.6%, would account for 65 ft or an expected distance of 1865. The maximum error due to the 1/2 sec update period would represent 95 ft. Thus, the recorded distance could reasonably be as high as (1865 + 95) 1960. The above data was within this range.

B. Complex Terrain Tests

Figures 8 through 14 show plots of the digital data recorded from the Flying Flagman for the seven simulated treatments over complex terrain. Each flight path is color coded with the direction of flight, color, flight number and letter code shown on the right margin of the graph. The exact data point is given by the flight number or letter. Again, any bad data was rejected and can be identified by a skip in distance between points.

Runs 1 and 2 were over Plots 1 and 2, respectively. These plots were over gently rolling terrain and the passes were from 200 to 300 ft above the ground level. On Run 1 the pilot used a needle sensitivity of 80 ft and had considerable difficulty in centering the needle. For example, on Pass 2 he started out

Table 5. Visual estimate of start and stop of spraying from edge of boundary, ft.

	Plot 2			Plot 3		
Pass	North End		South End	North End		South End
1		N → S		+ 99	N ← S	- 60
2		←			→	+ 39
3	-108	→		+108	←	0
4	+ 60	←	-108		→	+ 45
5	- 99	→	+ 60	+108	←	+ 39
6	+ 90	←	- 84		→	+ 54
7	-120	→	+ 87	+108	←	+ 39
8	+108	←	- 60		→	+ 45
9	-126	→	+105		←	+ 75
10	+108	←	- 39		→	+ 48

NOTE: - start or stop of spraying inside of plot boundary.

+ start or stop of spraying outside of plot boundary.

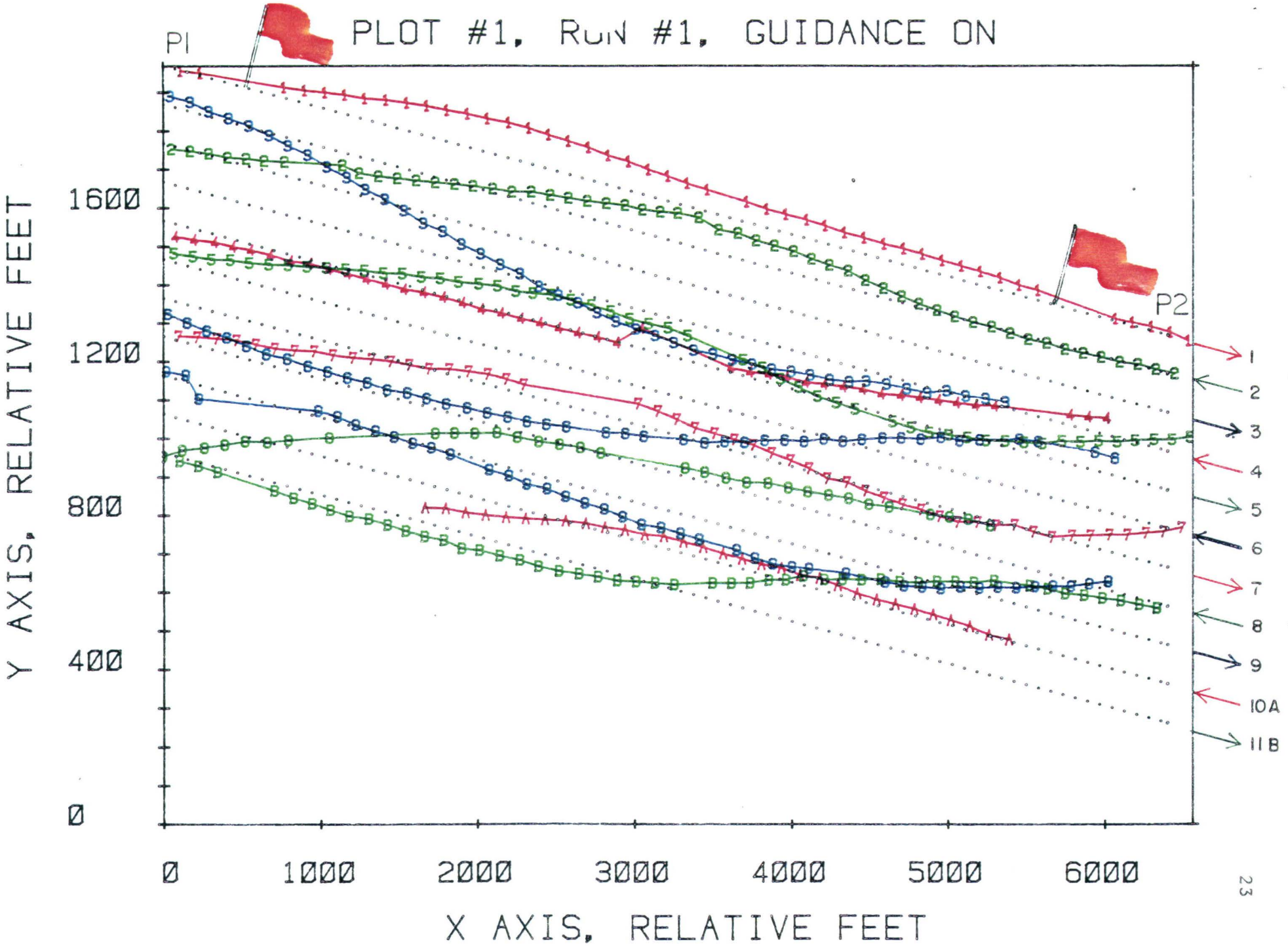
PLOT #1, RUN #1, GUIDANCE ON
P1
P2
Y AXIS, RELATIVE FEET
0
400
800
1200
1600
0
1000
2000
3000
4000
5000
6000
X AXIS, RELATIVE FEET
1
2
3
4
5
6
7
8
9
10A
11B

Fig. 8

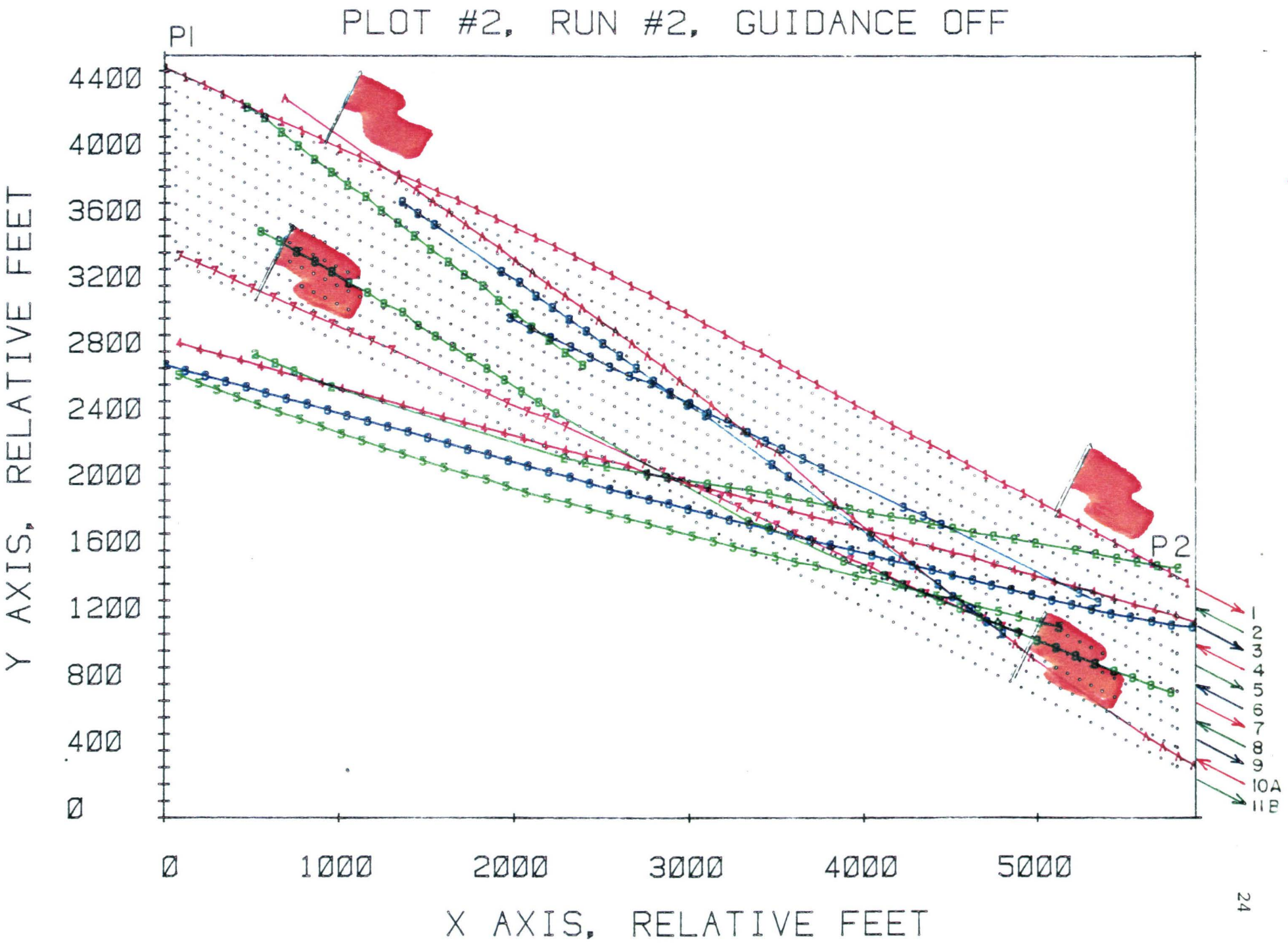
PLOT #2, RUN #2, GUIDANCE OFF
P1
P2
Y AXIS, RELATIVE FEET
4400
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
0
1000
2000
3000
4000
5000
X AXIS, RELATIVE FEET
1
2
3
4
5
6
7
8
9
10A
11B

Fig. 9

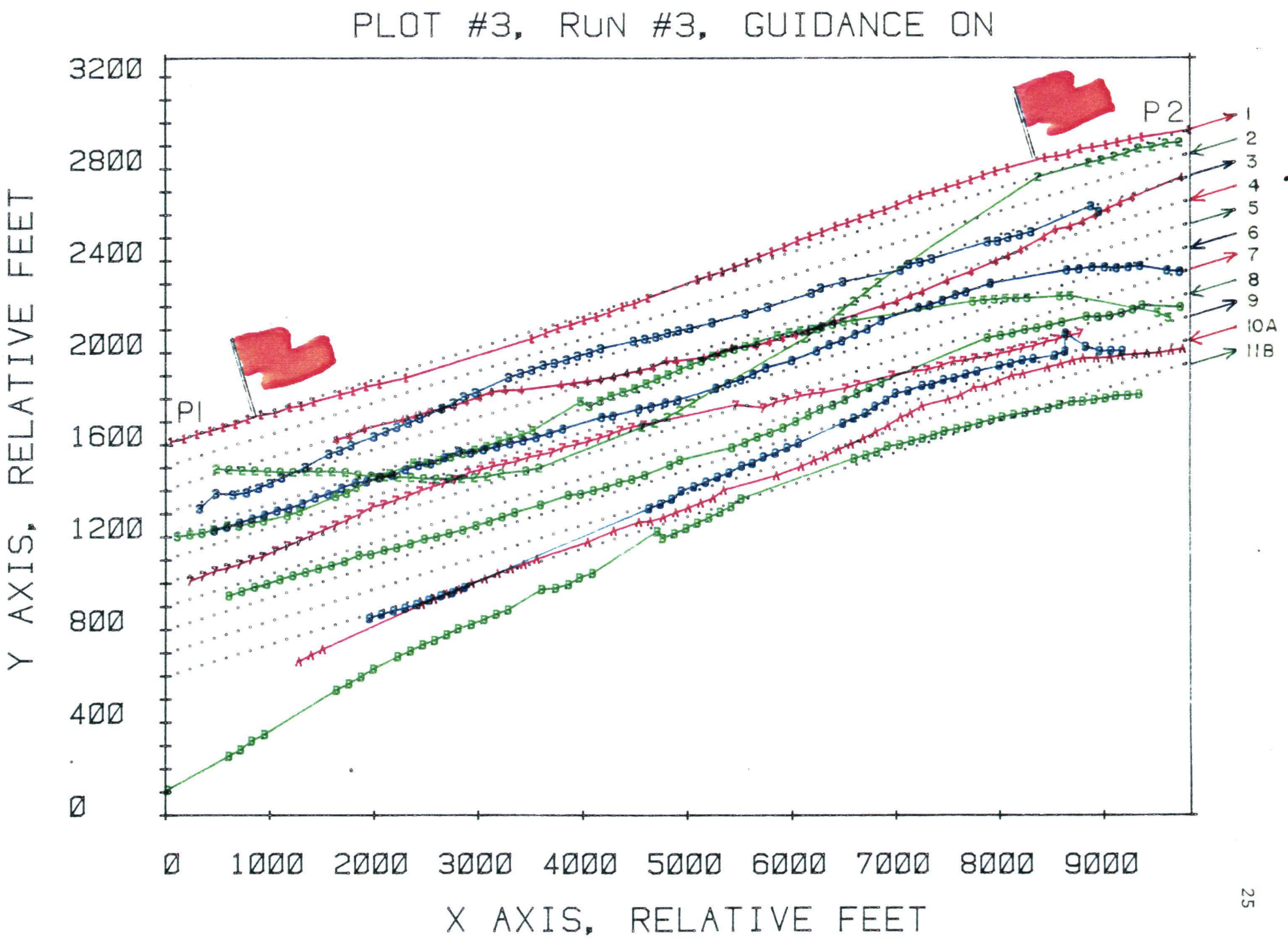
PLOT #3, RUN #3, GUIDANCE ON
Y AXIS, RELATIVE FEET
3200
2800
2400
2000
1600
1200
800
400
0
P1
P2
1
2
3
4
5
6
7
8
9
10A
11B
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
X AXIS, RELATIVE FEET

Fig. 10

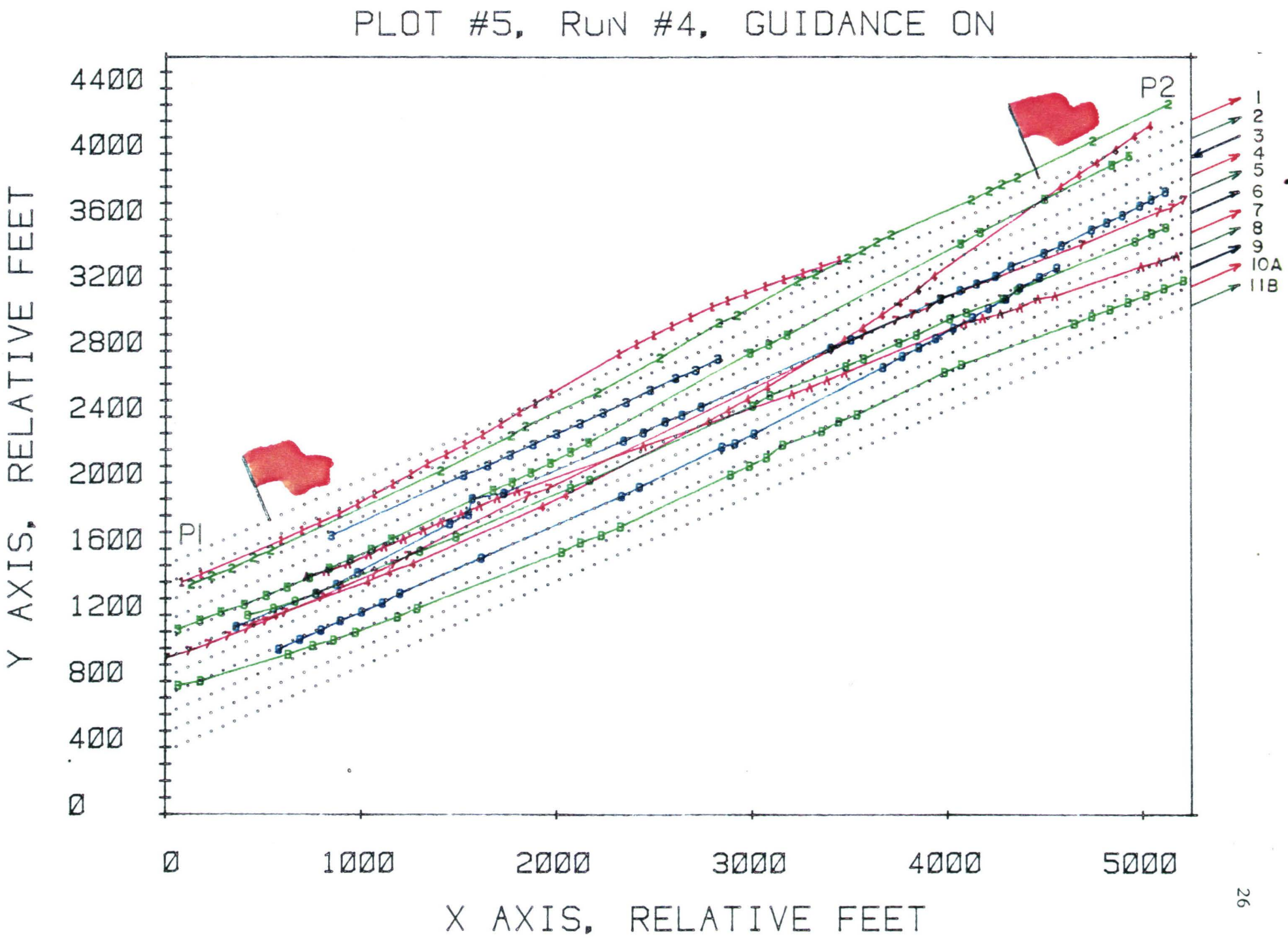
PLOT #5, RUN #4, GUIDANCE ON
Y AXIS, RELATIVE FEET
4400
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
P1
P2
1
2
3
4
5
6
7
8
9
10A
11B
0
1000
2000
3000
4000
5000
X AXIS, RELATIVE FEET

Fig. 11

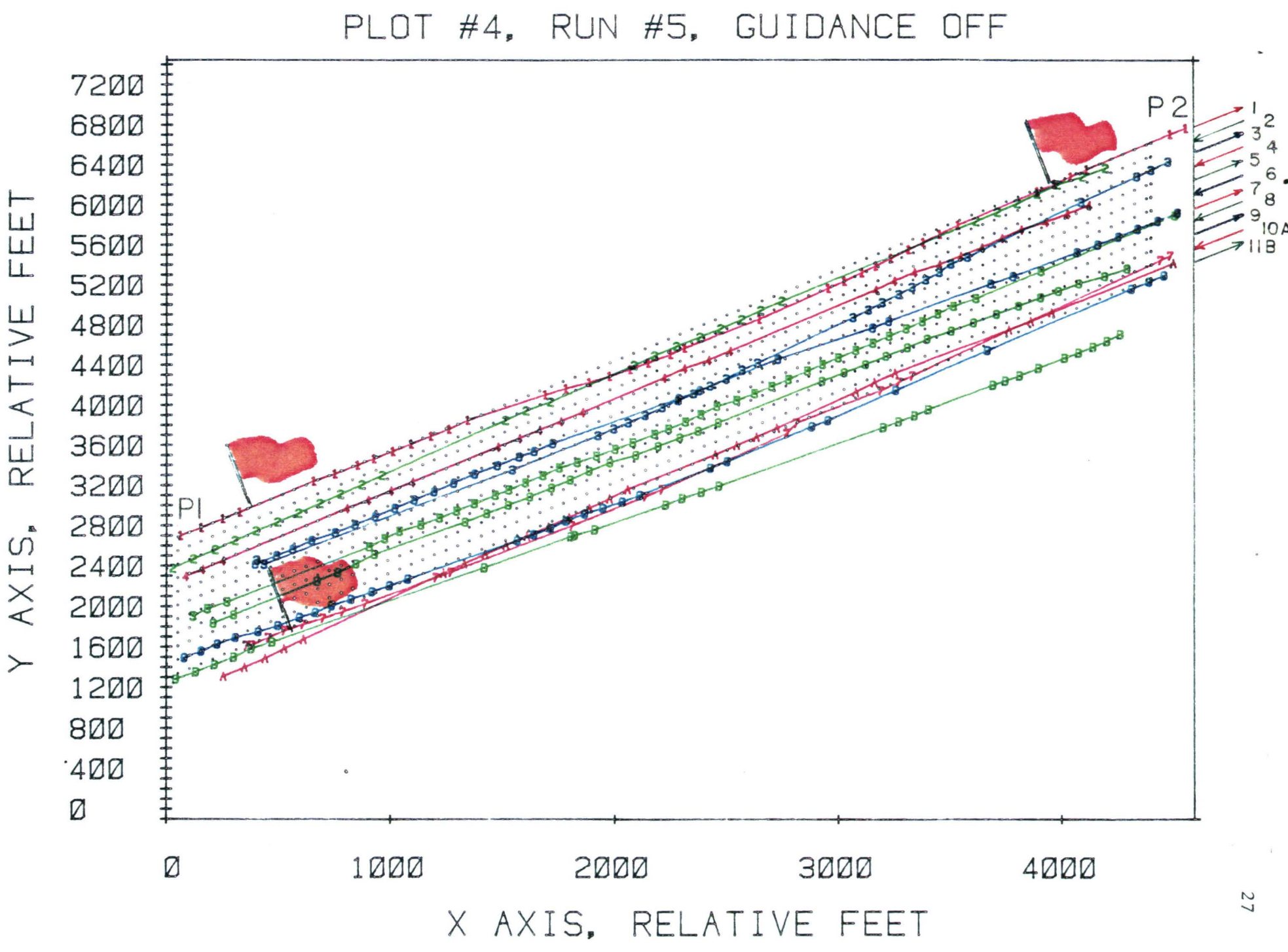
PLOT #4, RUN #5, GUIDANCE OFF
Y AXIS, RELATIVE FEET
7200
6800
6400
6000
5600
5200
4800
4400
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
P1
P2
1
2
3
4
5
6
7
8
9
10A
11B
0
1000
2000
3000
4000
X AXIS, RELATIVE FEET

Fig. 12

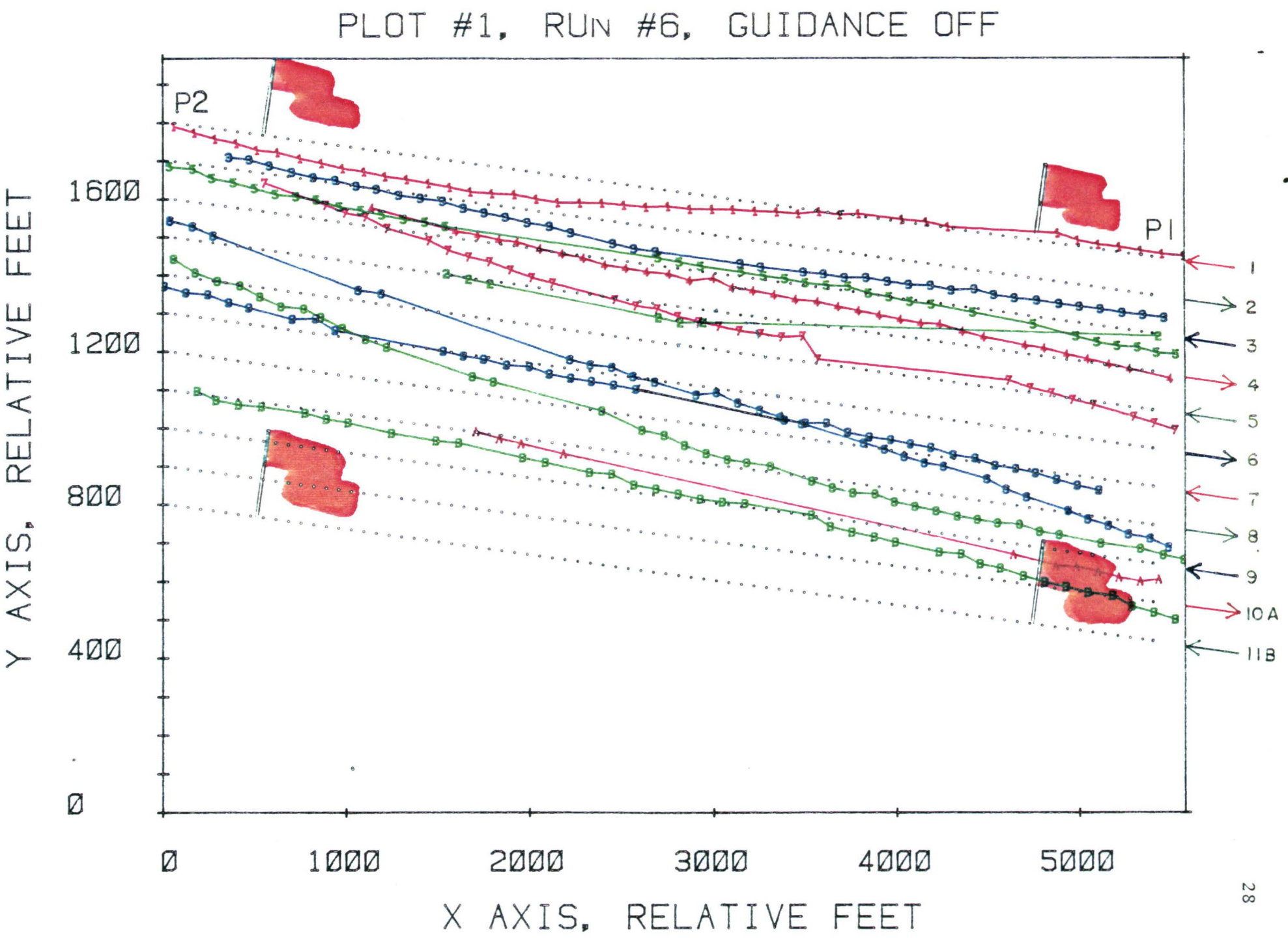
PLOT #1, RUN #6, GUIDANCE OFF
P2
P1
1
2
3
4
5
6
7
8
9
10A
11B
1600
1200
800
400
0
Y AXIS, RELATIVE FEET
0
1000
2000
3000
4000
5000
X AXIS, RELATIVE FEET

Fig. 13

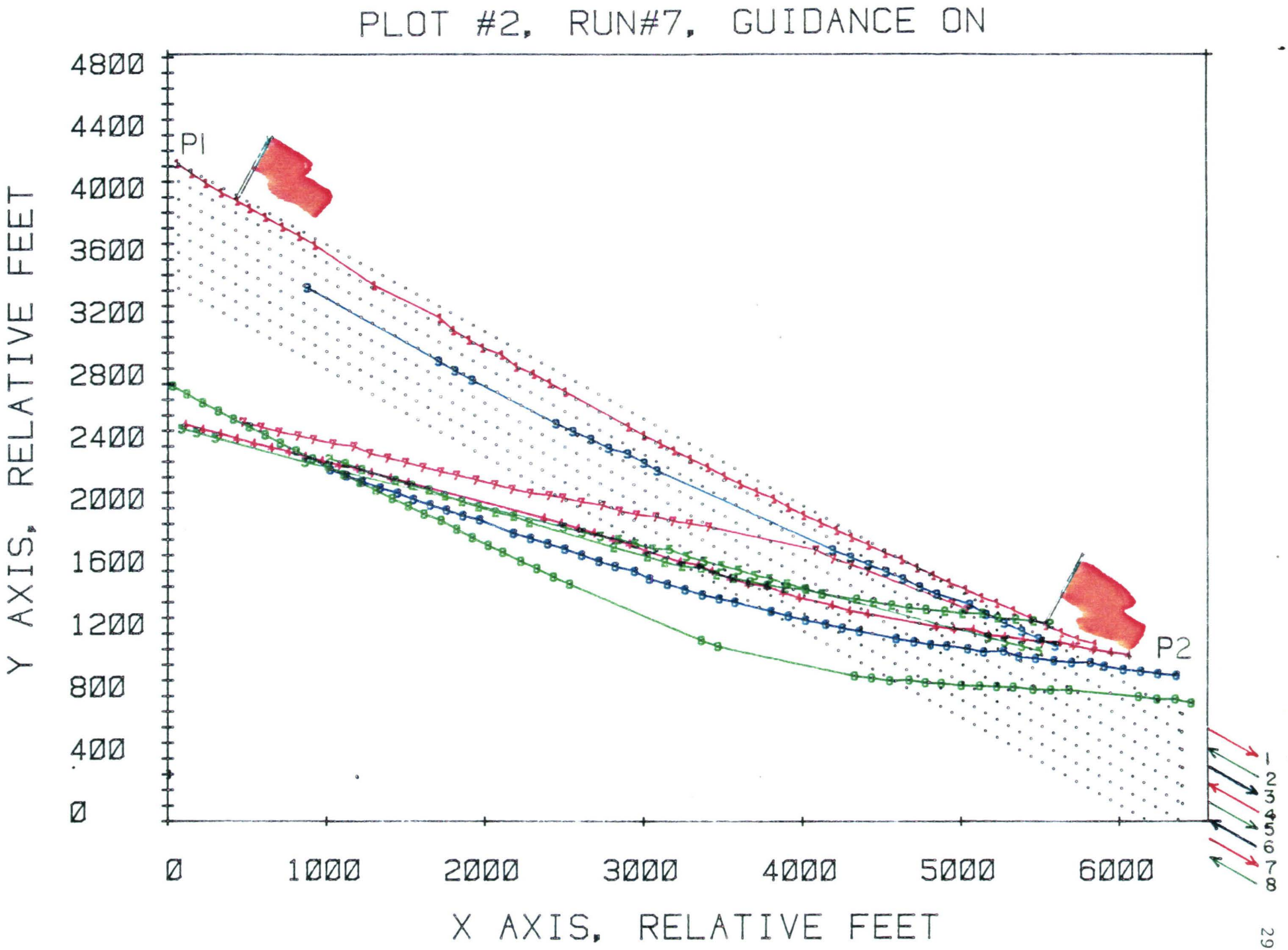
PLOT #2, RUN#7, GUIDANCE ON
Y AXIS, RELATIVE FEET
X AXIS, RELATIVE FEET
P1
P2
4800
4400
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
0
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
7
8

Fig. 14

on line, then he started to deviate to the right, next he over-corrected and progressed too far to the left. This type of wavy path seemed to be somewhat characteristic of the "Guidance on" runs. It should be noted that the paths generally progress in sequence and that although the pilot only had one border line, one flag on each P_1 and P_2, for Run 1, the desired width of the simulated application was very close to the desired width.

Run 2 was without the guidance system and illustrates the problems of human judgement. Generally, the paths are straight but may not progress in sequence. It was also evident that the pilot became disoriented and headed for the wrong flag on several passes.

Run 3 was with the guidance on and consisted of longer runs and over steeper terrain. Several passes showed frequent "loss" of data which would contribute to an irratic guidance needle. Again paths generally progressed in the correct sequence and finished very close to the desired width.

Run 4 was with the guidance on and was over some higher ridges. The pilot flew a racetrack pattern with the exception of one pass. The elevation above ground was 400 ft over the high ridge to 800 ft over the other end. There were frequent losses or skips in data on most of the passes.

Run 5 was without guidance and was over terrain similar to Run 4.

Runs 6 and 7 were back over Plots 1 and 2 but reversed with respect to guidance on and off. Run 6 was with guidance off and again showed problems flying the area in sequence.

Run 7 with guidance on should probably be disregarded. This was the last plot and the pilot was probably quite tired by this time. He seemed to lose the plot on the south end and gave up after the eighth pass.

Table 6 summarizes the deviations of flight paths from the theoretical evenly-spaced swaths for both the runs with and without the assistance of the guidance system. In general, the flights with the guidance system resulted in paths with less deviation from the desired paths. The average deviations from the theoretical paths with guidance on was 66, 78, 150 and 345 ft for Runs 1, 3, 4 and 7 compared to 375, 153 and 153 ft with guidance off on Runs 2, 5 and 6.

5. Conclusions

a. The output from the electronic guidance system can be recorded and the results can provide an excellent accurate record of the path of an aircraft.

Table 6. Complex terrain tests.

	Plot 1, Run 1, Guidance On			Plot 2, Run 2, Guidance Off		
Pass No.	Max. Dev. in feet	Min. Dev. in feet	Ave. Dev. in feet	Max. Dev. in feet	Min. Dev. in feet	Ave. Dev. in feet
1	93	0	50	96	0	51
2	109	0	37	1187	0	489
3	168	0	106	215	142	182
4	131	0	81	1132	0	521
5	154	0	48	1203	174	759
6	184	0	123	1087	0	491
7	113	0	32	367	123	238
8	309	0	88	149	0	55
9	122	0	37	723	34	408
10	61	0	23	1060	0	557
11	289	0	105			
Average Absolute Deviation	158	0	66	721	47	375

	Plot 3, Run 3, Guidance On			Plot 5, Run 4, Guidance On		
Pass No.	Max. Dev. in feet	Min. Dev. in feet	Ave. Dev. in feet	Max. Dev. in feet	Min. Dev. in feet	Ave. Dev. in feet
1	78	0	34	138	0	87
2	495	0	262	232	0	118
3	128	0	37	29	0	13
4	108	0	51	359	0	196
5	377	0	57	345	0	98
6	103	0	54	166	4	100
7	130	0	58	213	63	126
8	73	0	43	240	163	183
9	222	0	80	310	84	166
10	211	0	65	509	191	383
11	487	0	112	325	139	185
Average Absolute Deviation	219	0	78	261	59	150

Table 6 (cont.)

Pass No.	Plot 4, Run 5, Guidance Off			Plot 1, Run 6, Guidance Off		
	Max. Dev. in feet	Min. Dev. in feet	Ave. Dev. in feet	Max. Dev. in feet	Min. Dev. in feet	Ave. Dev. in feet
1	130	0	48	74	0	36
2	117	0	54	240	105	202
3	305	0	195	131	34	64
4	50	0	23	148	0	62
5	266	212	273	287	152	216
6	98	0	67	253	0	120
7	498	297	428	475	155	292
8	158	15	71	345	0	114
9	283	105	208	584	171	274
10	262	36	126	202	49	106
11	336	36	222	308	65	199
Average Absolute Deviation	228	64	153	277	66	153

Pass No.	Plot 2, Run 7, Guidance On		
	Max. Dev. in feet	Min. Dev. in feet	Ave. Dev. in feet
1	124	0	58
2	1088	0	536
3	191	0	104
4	1143	0	521
5	1076	0	368
6	754	0	410
7	653	0	319
8	794	0	443
Average Absolute Deviation	728	0	345

b. The electronic guidance system has the potential of providing pilot assistance that will result in a series of accurately-spaced swaths. One flatland plot was flown with an average deviation of 9% of the desired swath spacing.

c. Accurate calibration of the system is required if any basic component is changed. An error of 3.6% was observed in the plot width measurements.

d. The pilot did not have the capability to fly a series of parallel evenly-spaced lines in complex terrain.

e. The pilot did gain some assistance with the electronic guidance in complex terrain. With only two marker flags and the use of the guidance system the pilot maintained an average deviation of 66% of the swath spacing for the best test in complex terrain. The best the pilot could do under similar conditions without the electronic system and the use of 4 corner markers was an average deviation of 153%.

6. Cooperators

Pat Shea, U.S. Forest Service
George Markin, U.S. Forest Service
Gary Rockwell, Mgr., Carberry Dusters (Westside)
Roy Dillon, (Formerly) Carberry Dusters
Glen Smith, Carberry Dusters
Gail Nebker, Carberry Dusters
Harry Mitchell, Del Norte Tech.
Jim Gilmore, Del Norte Tech.
Paul Dano, Del Norte Tech.
Bob Cowden, UCD
Paul Horgan, UCD
Paul Christensen, UCD
Mark Marriott, UCD

7. Problems Encountered -- Suggestions for Follow-up Research

We do not know the reason why the pilot was not able to fly an accurate series of parallel lines in complex terrain. One or more of the possible reasons are: a) pilot did not have sufficient experience in mountainous terrain; b) the computer received too many rejected points that resulted in excessive movement of the needle; c) the guidance system needs a better display or communication link to the pilot.

The results from the flatland tests indicate that the system has the capability of providing assistance that can enable a pilot to fly a series of progressive parallel lines. Thus, the system does appear to have potential and follow-up tests would be desirable to clearly identify the problems and subsequently to improve the system for applications over complex terrain.

We suggest that another series of tests be conducted over complex terrain in the same area but with a pilot with more mountain flying experience. This series could be conducted at a relatively low cost because of our experience in the area, development and modifications of a recorder, and programming of our 9825 have been completed. Also, we have assurance from the Del Norte group that they would be willing to give some assistance by means of possibly providing additional transponders to enable placement of the units in locations with less interferences of signals from the aircraft.

It would also be desirable to conduct a series of tests with a helicopter. The lower speed and greater maneuverability could possibly enable the pilot to fly a series of uniformly spaced lines in complex terrain.

The above proposed tests would help to identify differences in pilot experience and also, if there is a significant difference in pilot performance between fixed wing and helicopter equipment.

If above tests do not produce consistent reliable patterns, a longer term basic research program should be initiated. One possible approach would be the development of a better communication link between the computer and the pilot. Several different systems such as new display systems, use of predicted paths, CRT displays of aircraft path and theoretical path, use of approach angles, etc, could be evaluated. The new electronic guidance systems appear to offer a great improvement in aerial applications over complex terrain.